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Verification of Taylor Impact Test by Using Force Sensing Block

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Abstract. In the Taylor impact test, obtained strain rate becomes in a range of 10^3~10^5/s corresponding to penetration of space debris to a space structure. According to this test, a stress value can be calculated by theoretical formulae. However, the formulae include some assumptions and the external force acting on a specimen is not directly measured by using the formulae. In the past study, the split Hopkinson pressure bar (SHPB) is employed instead of a use of a rigid wall which the specimen collides. However, there are two difficulties on this method. The first one is to be a similar range of measurable strain rate to the SHPB technique and the second is to require a sufficiently-large space for a testing apparatus. In contrast, by introducing a force sensing block, the apparatus becomes compact and longer measurable time is realized compared with the SHPB technique. Therefore, the stress value can be measured with higher precision since an extensive range of strain rate can be measurable. In this study, to enhance the precision of the test, it is suggested that the force sensing block is placed just behind the rigid wall for a direct measurement of a time history of external force.

Introduction

In the Taylor impact test, material is able to be deformed at strain rate in a range of 10^3~10^5/s. Over 10^5/s of strain rate is equivalent to deformation velocity in penetration of space debris to a space structure. The number of researchers using the Taylor impact test is increasing for various kinds of material since specimens can be deformed simply at such extremely-higher strain rate. [1]

Based on this test, a stress value can be calculated by theoretical formulae derived from the momentum balance. These formulae are assumed that a rigid wall collided with a specimen is a completely rigid; however, in fact, it is deformable. Therefore, it can be considered that errors are included in the stress value calculated by the formulae. Additionally, the calculation of the stress value becomes quite hard if the specimen made of brittle material fragments. [1] In order to obtain an accurate stress value, the external force acting on the specimen should be measured.

To solve above-mentioned problems and enhance the precision of this test, Lopatnikov et al. [2] proposed a method which the SHPB technique is introduced instead of the rigid wall and the specimen hits an end of a pressure bar directly. However, this method includes two difficulties. The first difficulty is to be a similar range of measurable strain rate to the SHPB technique and the second one is to require a sufficiently-large space for a testing apparatus. In contrast, by using with the force sensing block [3], this test is going to have two advantages such as more compact size and longer measurable time. Therefore, the stress value can be measured in higher precision since the testing apparatus becomes quite compact and extensive strain rate can be measurable.

In this study, at first, the testing apparatus based on the Taylor impact test is established. To comfirm a validity of results by the established apparatus, an impact compressive test based on the SHPB technique [6] is conducted at strain rate in a similar level of the Taylor impact test. To enhance a precision of the test, it is proposed that the force sensing block is installed just behind the rigid wall for a direct measurement of force with respect to time.

Experimental principle

Fig. 1 shows a schematic illustration of the testing apparatus based on the Taylor impact test. A cylindrical specimen launched from an air gun by releasing compressive air collides perpendiculaly against the rigid wall. Strain and strain rate generated in the specimen can be measured by using geometries of initial, deformed specimens and impact velocity. Fig. 2 shows a schematic drawing of the specimen before and after deformation. In this figure, L_0 is the initial length, L_f is the final length after impact, l_f is the length in the elastic part of the specimen, and v_0 is impact velocity. Nominal strain e and true strain ε of the specimen in the deformed part is calculated by the following equations,

$$e = \frac{L_f - L_0}{L_0 - l_f} \text{ and } \varepsilon = \ln(1+e) = \ln\left(\frac{L_f - l_f}{L_0 - l_f}\right). \quad (1)$$

True strain rate $\dot{\varepsilon}$ is calculated from the final shape of the specimen and v_0 as

$$\dot{\varepsilon} = \frac{v_0}{2(L_f - l_f)}. \quad (2)$$

In addition, theoretical formulae are derived from momentum balance for the calculation of the stress value. A choice of the formula depends on the reseacher since the formula calculating the most accurate stress is used for different materials in the test. Mainly, next three equations are employed for the calculation of true stress as,

$$\sigma = (1+e)\left\{\sigma_0 + \frac{[1-\beta(e)]^2}{e}\rho {v_0}^2\right\}, \quad (3)$$

$$\sigma = \frac{\rho {v_0}^2 (L_0 - l_f)}{2(L_0 - L_f)ln\left(\frac{L_0}{l_f}\right)}, \text{and} \quad (4)$$

$$\sigma = -\left(\frac{\rho {v_0}^2}{2}\right)\left[ln\left(\frac{\frac{L_f}{L_0} - 0.12}{0.88}\right)\right]^{-1}, \quad (5)$$

where σ_0 is the yield stress measured at strain rate in a quasi-static region and $\beta(e)$ is a parameter expressing work hardening behavior as a function of e. Eq. 3 requires to calculate additional parameters σ_0 and $\beta(e)$. In the past study, Hawkyard [4] mentioned that Eq. 4 is not accurate and proposed to correct Eq. 4 by using an extra parameter calculated from the final length of the specimen. Eq. 5 [5] is the most simple since no additional parameter such as the other equation is required.

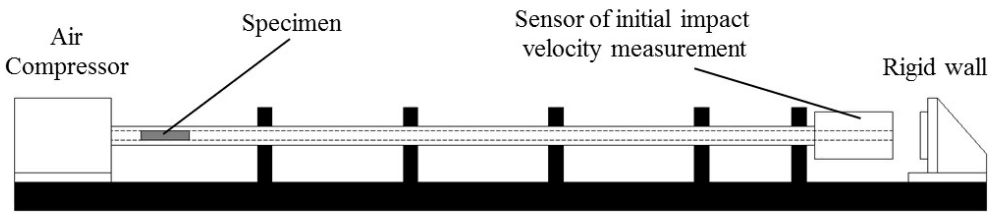

Fig. 1 A schematic drawing of a testing apparatus based on the Taylor impact test

Experimental method

Specimen. Material of specimens in this study is pure aluminum, A1070. The shape is a cylinder with 8mm in diameter and 40mm in length. The size is used generally in the test. [1] A shape of specimens used for the impact compressive test based on the SHPB technique is a disc with 8mm in diameter and 4mm in length.

Sabot. A sabot is a part to support the specimen for perpendicular impact against the rigid wall under guidance along the launcher. The specimen is inserted into the sabot and they launched together from the air gun. In general, brittle organic material is required for the material of the sabot since the sabot should possess lower mechanical impedance compared with the specimen and fragment easily at the moment of collision. Here, vinyl chloride is chosen. A shape of the sabot is a notched hollow cylinder with 8mm in internal diameter, 12.95mm in external diameter, and 25 or 30mm in length. The sabot is machined to be the hollow cylinder and the notch with 5mm or 10mm in length is introduced by a saw. The length of the notch depends on that of the sabot. An effective length of the sabot is determined by comparison of final shapes of specimens impacted at 111, 158, and 214m/s in impact velocity.

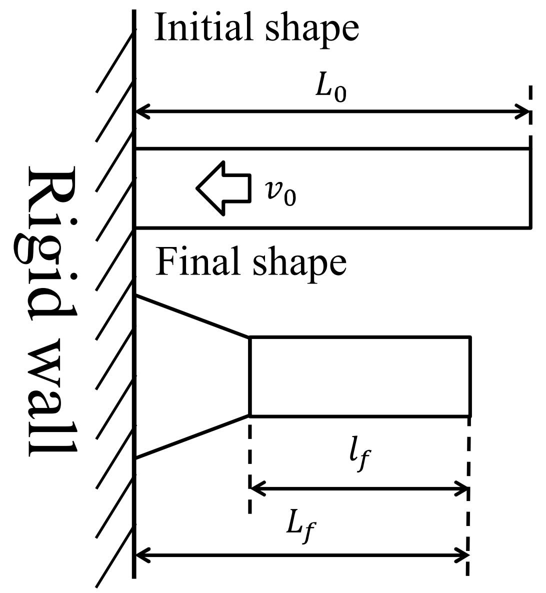

Fig. 2 Initial and final shapes of specimens

Established testing apparatus and its validly. In this study, a testing apparatus based on the Taylor impact test is established. A validity of the established apparatus is investigated by comparing with results obtained by the impact test based on the SHPB method [6] at 3100/s of strain rate. Since the SHPB technique is the most reliable in the range of strain rate from 10^2 to 10^3 /s and many research works by the technique for various kinds of materials have been done in the past [6], the more accurate value in stress can be measured by the SHPB technique. Fig. 3 shows a photograph of the established testing apparatus based on the Taylor impact test.

Introduction of force sensing block [3]. Material for the force sensing block is mild steel for industrial use, S45C. Fig. 4 shows a schematic illustration of the block. The block consists of two parts, a base block with 120mm in diameter and 50mm in length, and a sensing projection for a role as a load cell with 20mm in diameter and 30mm in length. Two strain gages are glued axisymmetrically at the center of the projection as shown in Fig. 4. The tests at 124, 146, 155, and 180m/s in impact velocity are conducted by using the modified apparatus with the block installed just behind the rigid wall. Fig. 5 shows a photograph of the manufactured force sensing block installed behind the rigid wall in the modified apparatus.

Fig. 3 Established testing apparatus

Finite Element Method

In this study, a commercial code MSC.Nastran ver. 2012.2 is chosen for the finite element analysis. A modified Johnson-Cook model by Allen et al. [7] is used as the material model of the specimen in the FE analysis. The modified Johnson-Cook model is expressed as follows,

$$\sigma = (A + B\varepsilon^n)\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^C\left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right]. \quad (6)$$

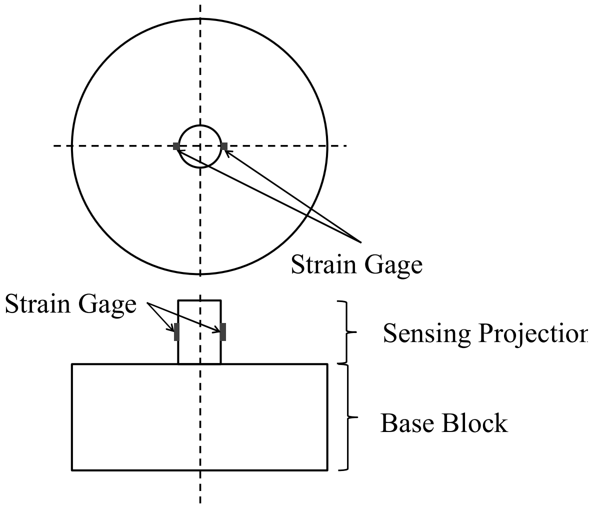

Fig. 4 A schematic drawing of force sensing block[3]

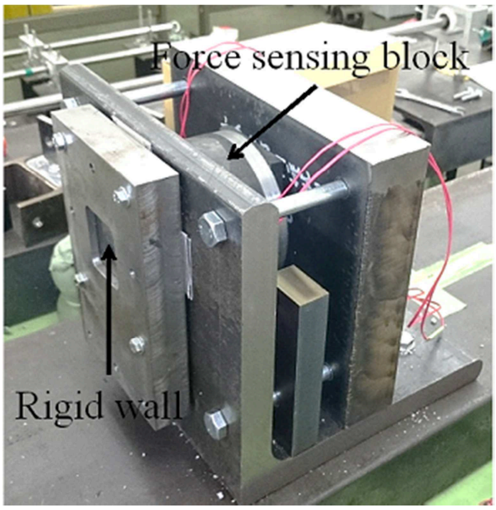

Fig. 5 The rigid wall installed behind the force sensing block

Identified parameters in the above equation are shown in Table 1. Fig. 6 shows the FE model of the Taylor impact test. The FE model consists of the specimen, the rigid wall, and the force sensing block as shown in this figure. Constraint conditions for the displacement are introduced to create the quarter model according to symmetric deformation including the other condition. A finite element used here is a hexahedral isoparametric linear element with 8 nodes. The total number of nodes and elements are 80462 and 76700, respectively. Additionally, the stiffness form with exact volume integration proposed by Flanagan and Belytschko [8] is employed to suppress the hourglass mode. At the interfaces between the specimen, the rigid wall and the sensing block, contacts are defined. The rigid wall is assumed to be a linear elastic body with 14500kg/m^3 in density, 559GPa in Young's modulus and 0.22 in Poisson's ratio for tungsten carbide. The force sensing block is assumed to be a linear elastic body with 7900kg/m^3 in density, 210GPa in young's modulus, and 0.3 in poisson's ratio for S45C. The FE analyses of the Taylor impact test at 80, 100, 150, and 200m/s in impact velocity is performed.

Table 1 Parameters of the modified Johnson-Cook model

A [MPa]	*B* [MPa]	*n*	*C*	*M*
83.5	28.03	0.34	0.03	0.83

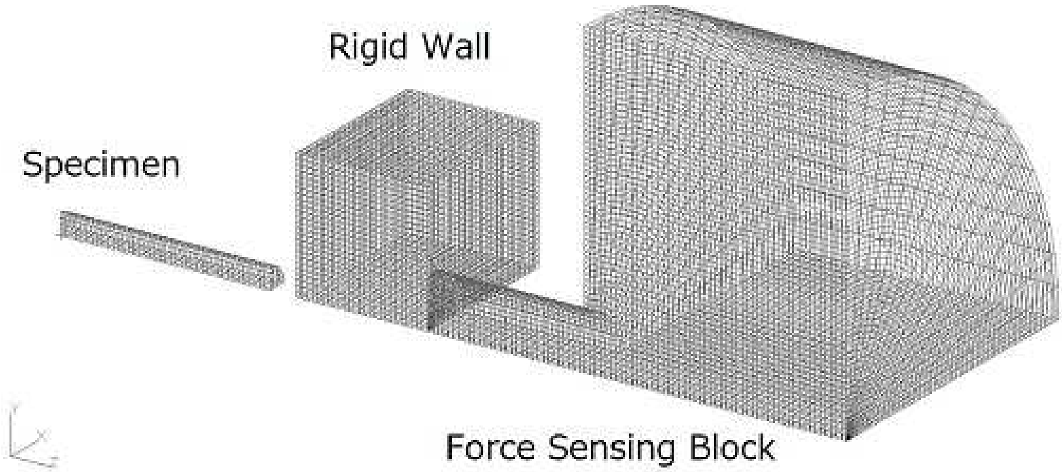

Fig. 6 FE model of the Taylor impact test

Results of experiments and analyses

Determination of dimensions for the sabot. The effective length of the sabot can be determined by observing two following kinds of appearance about the final shape of the specimen. The first is a shape without abnormal bending deformation. This means that the specimen collides with the rigid wall perpendicularly. The second is a shape without any constraints to deform in radial direction. Fig. 7 shows the final shape of specimens for two lengths of sabots. As shown in this figure, the second cannot be observed for all the specimens. Moreover, the first one can be only observed in the case of the sabot with 25mm in length at impact velocity of 214m/s. Thus, it can be considered that the sabot with 30mm in length is appropriate in this study.

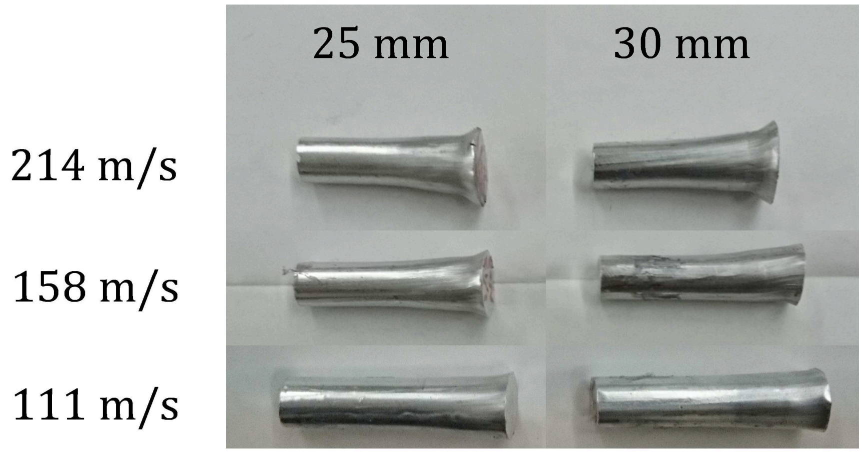

Fig. 7 Comparison of final shape of specimens

Validity of testing apparatus and a choise of formula. Fig. 8 shows a stress-strain diagram obtained by using the established apparatus based on the Taylor impact test, FEA, and the SHPB technique. In this figure, the black line indicates the result of the SHPB method at 3100/s, circles are results of the Taylor Impact test at 3100/s, squares denote results of the Taylor impact test in the range of strain rate from 3500 to 5600/s, and triangles indicate results of FEA. In addition, colors of marks depend on formulae used for the calculation of stress value. That is, results of Eqs. 3, 4 and 5 are showed by red, blue, and green marks, respectively. As shown in this figure, the stress-strain relationship obtained by the Taylor impact test and FEA shows good agreement. In addition, stress calculated by Eqs. 4 and 5 corresponds to that obtained by the SHPB technique at the same strain rate of 3100/s. Therefore, Eqs. 4 and 5 are the appropriate formulae to express the stress-strain curve for the specimen made of A1070. In this study, it is determined that Eq. 5 is the most appropriate since it is the most simple as mentioned above. From these results, established testing apparatus in this study is valid.

Taylor impact test by using force sensing block. Fig. 9 shows the time history of external force measured by using the force sensing block. As shown in this figure, the measurement of external force with respect to time is succeeded. The external force increases with increasing the impact velocity and the time duration of the force is independent on impact velocity.

Summary

A purpose of this study is to enhance the precision of Taylor impact test by using the force sensing block. At first, testing apparatus based on the Taylor impact test was established. At same time, impact compressive test based on the SHPB technique was conducted at strain rate in the similar level of the Taylor impact test. Then, the validity of testing results by the established apparatus was confirmed by comparing the results from two methods. As a result by using the sensing block, a measurement of external force with respect to time was succeeded. In near future, stress value will be calculated from the time history of external force measured in this study for impact compression tests to calculate a stress-strain curve. In addition, the time history of strain will be measured from deformation behavior of a specimen observed by a high-speed camera. Eventually, it is prospective that a plot of the stress-strain curve at extremely-higher strain rate will be possible in only one time of the test derived from time histories of stress and strain.

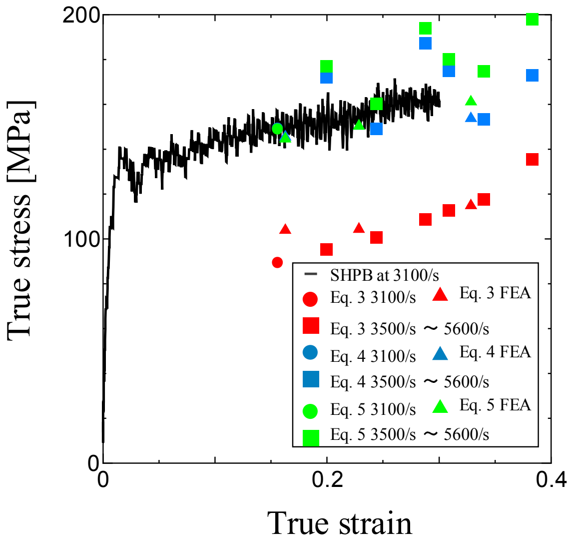

Fig. 8 Comparison with results obtained by SHPB method and Taylor impact test

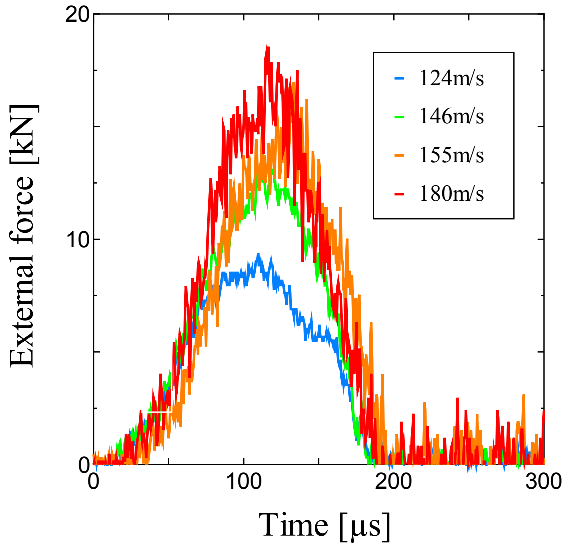

Fig. 9 The time history of external force obtained by the force sensing block

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References

[1] R. Julien, T. Jankowiak, A. Rusinek, P. Wood, Taylor's test technique for dynamic characterization of materials: Application to brass, Exp. Tech. **38-**1 (2014), to be appeared.

[2] S. L. Lopatnikov, B. A. Gama, M. J. Haque, C. J. Krauthauser, W. Gillespie Jr., M. Guden, I. W. Hall, Dynamics of metal foam deformation during Taylor cylinder‑Hopkinson bar impact experiment, Compos. Struct. **61** (2003) 61‑71.

[3] Y. Chuman, K. Mimura, K. Kaizu, S. Tanimura, A sensing block method for measuring impact force generated at a contact part, Int. J. Impact Eng. **19-**2 (1997) 165-174.

[4] J. B. Hawkyard, A theory for the mushrooming of flat-ended projectiles impinging on a flat rigid anvil, using energy considerations, Int. J. Mech. Sci. **11** (1969) 313-333.

[5] M. L. Wilkins, M. W. Guinan, Impact of cylinders on a rigid boundary, J. Appl. Phys. **44** (1973) 1200-1207.

[6] T. Iwamoto, T. Yokoyama, Effects of radial inertia and end friction in specimen geometry in split Hopkinson pressure bar tests : A computational study, Mech. Mater. **51** (2012) 97-109.

[7] D. J. Allen, W. K. Rule, S. E. Jones, Optimizing material strength constants numerically extracted from Taylor impact data, Exp. Mech. **37**-3 (1997) 333-338.

[8] D. P. Flanagan, T. Belytschko, A uniform strain hexahedron and quadrilateral with orthogonal hourglass control, Int. J. Numer. Meth. Eng. **17** (1981) 679-706.

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